[1]PHOTOELECTRIC AND IONIZATION DETECTORS - A REVIEW OF THE LITERATURE - RE-VISITED

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INTRODUCTION

In 1998, a paper titled "Photoelectric And Ionization Detectors - A Review Of The Literature"[1] put forth the following propositions:

1. That ionization detectors were potentially inadequate at detecting smoke from smoldering fires,
2. That this phenomena had been observed in research that was available in the published literature,
3. That this was a hidden problem, in part due to a failure of the UL 217[2] test to adequately test for the kind of smoke given off by modern furniture, and
4. That the Indiana Dunes[3,4] test had to be redone using current detector technology as well as current furniture using synthetic materials.

In 2000, a paper titled, "Smoke Detectors and the Investigation of Fatal Fires"[5], expanded on the arguments presented and cited several additional studies to support the propositions. This paper also raised questions about the way we collect information regarding smoke detectors. It suggested that Incident Commanders at fires, i.e. Fire Chiefs, as well as most fire investigators did not account for important variables regarding detector effectiveness.

This paper will review the validity of the propositions put forth in these papers as a result of the recent Home Smoke Alarm testing performed by NIST[6]. (The report discussing the results of this test has been made available on the Web, (www.smokelarm.nist.gov/). To make it easier for those who would like to read the NIST report for themselves this paper will list the page number of any key information from the report that is referenced.)

To properly understand the NIST results, one has to understand the results of previous studies that looked at detector effectiveness as well as the available statistics dealing with detector effectiveness. As a consequence, this paper will be broken down into three parts. Part One will review the historical studies that looked at detectors and compare those results to the current NIST studies. Part Two will analyze the available statistics to see if they support the results of the NIST tests. Part Three will look at the validity of the UL217 Approval tests in light of the results from the NIST Tests.

PART ONE - DETECTOR STUDIES

In the Introduction, the recent NIST Report[6] states, "The results obtained were similar to those of the earlier work. Both common residential smoke alarm technologies (ionization and photoelectric) provided positive escape times in most fire scenarios with the ionization type reacting earlier to flaming fires and the photoelectric type reacting earlier to smoldering fires."

These comments seem to be making two main points:

1. That ionization and photoelectric detectors are qualitatively equal and
2. This result is similar to results achieved in earlier work dealing with the effectiveness of smoke detectors.

When the authors of the NIST Report refer to "earlier work" they appear to be referring to earlier work that was "published in the open literature". A statement, included later in the report, supports this interpretation. "In this period, reports surfaced that some privately funded testing had shown delayed response from smoke alarms using ionization-type sensors to smoldering fires. While detailed reports were never published in the open literature, these persistent reports were the cause of some concern." Clearly the authors only intend to refer to published literature. In particular the authors seem to be referring to the Indiana Dunes Research [3, 4] that was conducted in the mid-70's. However, both papers listed earlier [1, 5], were detailed reports that were published in the open literature and referenced many studies that showed a delayed response of ionization detectors to smoldering smoke**.** In addition**, every study** referenced by these papers, which showed, "delayed response from smoke alarms using ionization-type sensors to smoldering fires," came from the open literature. Thus the claim that no information ever appeared in the open literature, regarding this problem, does not appear accurate.

This paper will attempt to conduct an analysis of the publicly available literature that takes into account the following key factors.

1. Detector technology in place at time of testing.
2. Nature of material burned, i.e. synthetic or natural, and
3. Duration of smoldering scenario.

<u>Analysis of Historical Detector Studies</u>

An article published in 1993[7] reached the following conclusion after reviewing the "open literature" pertaining to smoke detector research. (This article, written by NIST Staff, was referred to by NIST at some of the planning meeting for the recent testing so it is fair to assume that NIST still considers the analysis valid.)

> "All of the studies presented conclusions that were essentially identical: When either ionization or photoelectric detectors are located outside the bedrooms and on each level they provide adequate warning to allow the occupants to evacuate through their normal egress routes."

A summary 18 different studies, all of which appeared in the "open literature," is contained in Appendix A. The studies listed include every study discussed in the 1993 article as well as some additional studies. The additional studies discussed include the following: two conducted prior to the cut-of date of 1991 that were left out, and five that were conducted after the cut-off date of 1991.

An analysis of the studies cited indicated that the majority occurred in the 70's, prior to the adoption of many of the current test required by UL 217. (#1 - #12) In at least one study only flaming fires were analyzed. (#10) Two of the studies cited were merely statistical survey in which no actual testing was performed. (#1 & #7) The 1986 Australian Research was referenced by the 1993 article, but it was not discussed because, "only smoke detectors were tested". (#13) The testing conducted by the Los Angeles Fire Dept., the CALCHIEFS Tests, was also mentioned but only to point out that it showed that, "smoke detectors are more reliable than heat detectors". In addition, in discussing the results of the CALCHIEFS' tests this analysis neglected to include 2 documents that appeared in the open literature, prior to the cut-off date, that raised concerns about ionization detectors based on these LAFD tests. (See references 13, and 14 in Appendix A.)

As opposed to the NIST analysis, which concluded that the publicly available studies support an opinion that there is no qualitative difference between ionization and photoelectric detectors, an analysis of the studies contained in Appendix A, taking into account the three factors listed earlier can be used to support the following statement:

> ***Residential smoke detector tests for the past 3 decades from 4 different countries, that used synthetic furnishings and smoldered fires for at least 30 – 45 minutes, concluded that ionization detectors were inadequate for smoldering scenarios. (See Appendix A, studies numbered: 5,8,11,12, & 14). Several other studies which either smoldered fires for shorter periods or simulated fires in a test room, nevertheless, reached similar conclusions (See Appendix A, studies numbered: 10, 13, & 17). No study concluded that photoelectric detectorss, with current "open" design, were inadequate for flaming or smoldering.***

Here are sample quotes from research that appeared in the published literature over the past 25 years.

A study was conducted in 1978 in England[8] to study the effectiveness of fire detectors installed in bedrooms and corridors of residential institutions.

The smoldering fires were started using a cigarette placed between pads of fibrous cotton upholstery wadding. A polyurethane mattress was covered with cotton sheets. The flaming fires were started with crumpled newspapers, primed with ethanol that was placed under the side of the armchair nearest the bed.

Some of the conclusions of the researchers in this study were the following:

- Under the conditions of ignition from flames, the ionization chamber type detector exhibited a greater sensitivity to the smoke produced than the photoelectric system. However, the rate of generation of smoke was so great that the extra time given by the ionization chamber as a result may be of little practical use.
- Ionization chamber type detectors, in the room of origin and the corridor, did not, in the smoldering fire tests, provide adequate warning that the escape route was impassable or that conditions in the room were potentially hazardous to life.

In 1980 a special committee of the International Association of Fire Chiefs reached the following conclusions regarding testing conducted by the Los Angeles Fire Dept. [9]

> "This test will show that most photoelectric detectors, operated by battery will detect smoke at about 1.5-3% smoke, which is good. The test will show that the photoelectric detectors operated by household current will activate between 2 and 4 %, which is still good. But, the test also will show that many ionization detectors will not activate until the smoke obscuration reaches 10-20 and sometimes 25%. … Therefore, because of the present state of the art in detecting smoke, the Subcommittee on Smoke Detectors can take no other course but to recommend the installation of photoelectric detectors."

Researchers in Australia reached similar conclusions in 1986[10.] They investigated smoke detectors ability to detect smoldering fire in a typical residential dwelling. The smoke used in the test was generated from hardwood smoldered on a hot plate and artificial smoke meant to copy the smoke from smoldering fires as well as high smoke evolution which could arise in an arson fire. Their conclusions were the following:

- Photoelectric detectors sighted in the hallway are more effective for detecting smoldering smoke than ionization detectors, providing adequate escape time for most conditions of size and location of the smoke sources.
- Ionization detectors sited in the hallway generally provide inadequate escape times unless smoke movement into the hallway is slowed down by narrow door openings, causing a slower loss of visibility, or unless they are sited close to the smoke source.

In 1991 Norwegian researcher[11] placed smoke detectors inside and outside the room of origin. The flaming fires were started with a Methenamine, 1588 source. The smoldering fires were started with a glowing cigarette placed on a textile. They obtained the following results.

They reached the following conclusions.

- The ionization detectors detected smoke from a smoldering fire much later than optical (photoelectric) detectors. When the particular conditions during the fire development are taken into consideration there are reasons to indicate that this detection principle would not provide adequate safety during this type of fire.
- In many countries like Norway, 90-95% of the smoke detectors installed in homes are ionization types of detectors. Here, smoldering fires are often caused by smoking and those who have installed such detectors are satisfactorily safe providing measures are made to prevent smoldering fires from starting. This means smoking in bed must be avoided. If such homes are to purchase new detectors, the recommendation is that the optical smoke detector is needed.
- For individual room surveillance, such as in hospitals and hotels, optical (photoelectric) detectors should always be used. Even though these detectors are slightly less responsive when detecting smoke from flaming fires in a room, this time margin should be related to the greater safety optical (photoelectric) detectors provide when smoldering fires occur. The advantage of ionization smoke detectors during flaming fires is only about a 15-20 second earlier warning. This margin will only be decisive for the loss of human life in extraordinary circumstances.

The NIST Report[6] was correct in stating that the research conducted at Indiana Dunes showed that ionization and photoelectric detectors provided qualitatively similar response to different scenarios. However, as pointed out in the paper titled "Photoelectric And Ionization Detectors - A Review Of The Literature"[4], the testing at Indiana Dunes had a couple of key differences from other tests that were conducted from the late 70's or later.

1. The detectors used were pre UL217 detectors. In addition, the photoelectric used at Indiana Dunes, with one exception, did not utilize the "open design" that today's photoelectric utilize. (Since the early 80's photoelectric detectors have used LED technology, which allowed manufacturers to open up the design and let ambient light, as well as smoke, to more easily enter.)
2. The upholstered furniture was primarily filled with cotton material as opposed to synthetic material. The fact that, the Dunes test did not use synthetic materials was actually noted by the researcher's, at Indiana Dunes, who pointed out, "Further study is needed of detectors exposed to synthesized fires in real residences."[4] Unfortunately, this research need seems to have been forgotten until discussed in the 1998 paper[1] mentioned at the beginning of this paper. The recent NIST Testing finally addressed this issue, <u>over 30 years after it was first identified, as a research need.</u>

Since the recent NIST Testing also used synthetic furniture and smoldered fire for more than 30 minutes it is critical to analyze the recent NIST results to determine if they "are similar to earlier work".

NIST Results[6]

The authors are correct in stating, "Both common residential smoke alarm technologies (ionization and photoelectric) provided positive escape times in most fire scenarios". This statement, if true, would make the result consistent with the results at Indiana Dunes. However, it is important to point out that although it is true that a positive escape time was provided in most fire scenarios it is also true that in some fire scenarios a positive escape time was not provided. As is often the case, the exception to the general rule is far more interesting than the rule itself. In addition, positive "escape times" are less important than positive "margins of safety" in determining smoke detector adequacy.

Table 1 summarizes some of the information contained in Tables 27 and 28 of the recent NIST Study[6] for the scenarios when it was assumed that there was one smoke detector per level, the predominant installation pattern in existing residential settings.

TABLE 1 - AVAILABLE SAFE EGRESS TIME (PAGE 242)
(Manufactured Home)

	Photoelectric	Ionization
Flaming		
Living Room	85	142
Bedroom	58	93
Bedroom (Door Closed)	451	898
Smoldering		
Living Room	172	-43
Bedroom	1091	82
Cooking		
Kitchen	575	821

TABLE 2 - AVAILABLE SAFE EGRESS TIME (PAGE 243)
(Two-Story Home)

	Photoelectric	Ionization
Flaming		
Living Room	108	152
Living Room(Replicate)	134	172
Living Room(Fully Furnished)	144	172
Bedroom	---	374
Bedroom (Door Closed)	3416	3438
Smoldering		
Living Room	3298	16
Living Room (Air Conditioned)	2772	-54
Bedroom	135	135
Cooking		
Kitchen	952	278

While the NIST Report provides detailed information regarding the Available Safe Egress Time (ASET) results, the report fails to point out that in several important scenarios the ionization did not appear to give adequate warning. In 2 out of the 3 smoldering scenarios in the Living Room the Ionization detector provided negative "Escape Time". In the 3rd Scenario the "Escape Time" was only 16 Seconds. This "exception to the rule" that most scenarios provide positive escape is critical since this scenario is cited by the NIST Report as the Number One Scenario ranked by number of deaths. (see Table 9.)

Specific Information on one of the smoldering test is illustrated in Figure One[12]

FIGURE 1 - NIST RESULTS(TEST 34)

Smoldering Furniture in Living Room

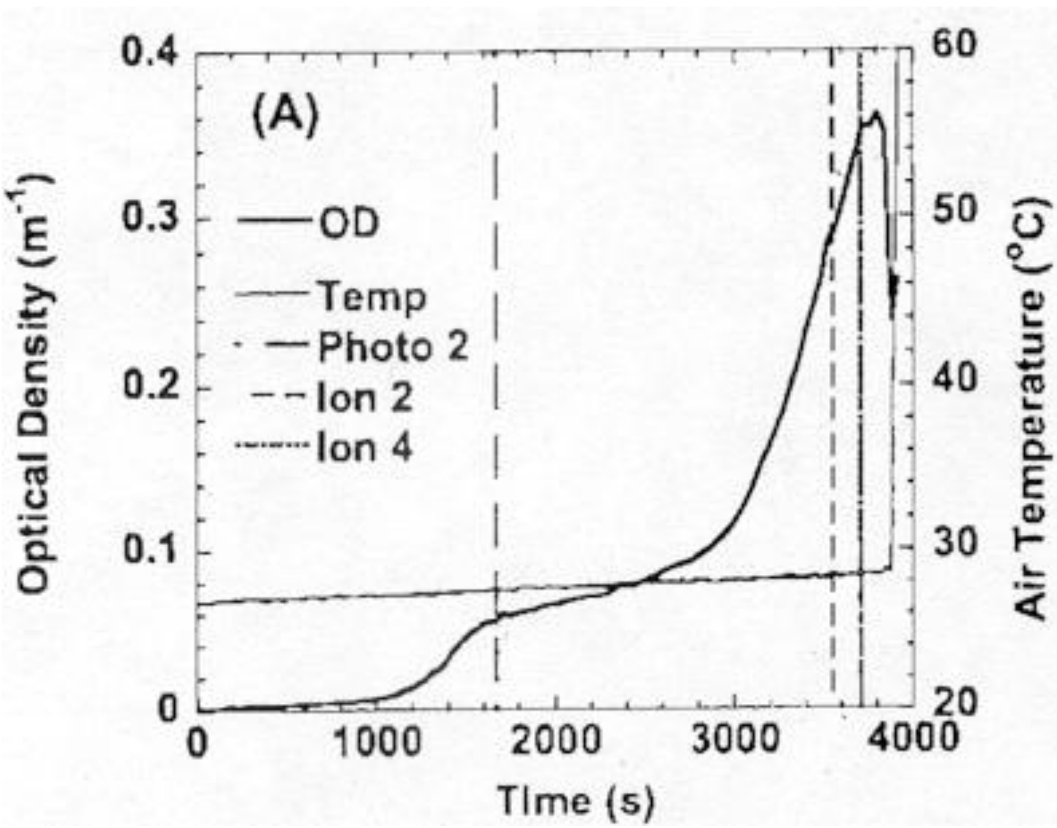

TABLE 3 – RESPONSE CHARACTERISTICS (TEST 34)

DETECTOR TYPE	RESPONSE TIME	%OBSCURATION AT RESPONSE
Photoelectric	1600 secs	3-4% obsc/ft
Ionization	3550 secs	17-19% obsc/ft
Ionization	3700 secs	20-22% obsc/ft

It is evident that the ionization detector is not responding until obscuration levels that far exceed the 10% passing criteria in the UL 217 Smoldering Test. (This phenomenon was predicted in the 98 paper[1]. The reasons will be re-examined in this paper.) If one uses a 2-minute escape time and a tenability criteria of 0.25 OD/m then a detector would have to respond at approximately 10-12% obscuration per foot in order to provide the occupants adequate escape time. NIST originally proposed to use 0.5 OD/m and an interface height less than or equal to 1.0m as a tenability criteria.[13] They eventually chose 0.25 OD/m at a height of 1.5 m. [6] This second, and final, tenability criteria seems more appropriate since it allows consistency with and comparison to the results at Indiana Dunes. This criterion is also supported by published studies. [14, 15] The lower level, i.e. 0.25 OD/m is particularly valid for smoldering fires since the type of smoke produced in smoldering fires tends to be more irritating than the type of smoke given off in flaming fires. [14]

This was the approach used by Harpe and Christian, the developers of the original UL217 Smoldering Test, to determine the original passing criteria of 7% utilizing data from Indiana Dunes.Harpe and Christian[16] collected data from the Indiana Dunes Tests. They compared the "Estimated Success Frequency" vs. the "Detector Response Sensitivity". Success was defined as detector activation 2 minutes or more before the first occurrence of untenability on any primary escape route. When the detector was located on the same level as the fire then the detector's success rate was: approximately 95% successful detection if it activated at 10% obscuration per foot, approximately 70% successful detection if it activated at 15% obscuration per foot, and approximately 50% successful detection if it activated at 20% obscuration per foot. (The ionization detectors, in Figure One, responded in the range of 17-22%)

Figure 1also supports the findings by several of the researchers listed in Appendix A (#15 & #18) that regardless of the smoke thickness the ionization detector may not respond until flames appear. While the exact point of transition to flaming is not identified it is not unreasonable to assume that it occurred shortly before the spike in temperature at approximately 3900 seconds. This would make it concurrent with the operation of the ionization detectors. It is not until flaming occurs that enough small particles are generated to cause an ionization detector to respond. This is an important result. In fires that smolder for more than 30-45 minutes, particularly fires in bedrooms the occupants could be impaired by Carbon Monoxide.

The result of these recent tests, which indicate that the ionization detector is not responding in time, differs from the earlier test at Indian Dunes, which indicated that they did. Both the earlier testing and these more recent tests appear to show that the photoelectric is adequate for both types of fires. The NIST Report[6] states that the main difference in the amount of escape time in these modern test as opposed to the earlier test is due to:

1) Different, tenability criteria (It is implied that the tenability criteria in the most recent testing is more conservative.)
2) Fire growth rates are significantly faster.

Thus, it is important to analyze these two factors.

TABLE 4 - FIRE GROWTH RATES (Page 248 of NIST Report)

	1975 TESTS[3, 4]	CURRENT[6]
Flaming	**1043 +/- 365 Seconds**	**169 +/- 37 Seconds** ***(84% LESS)***
Smoldering	**4146 +/- 1961 Seconds**	**3303 +/- 1512 Seconds** ***(20% LESS)***

While it is true that the fire growth rate for flaming fire is much faster than the 1975 test, the growth rate for smoldering fire is not that much different. In fact, NIST states that, "Average times for smoldering fires in the current test series were comparable to those observed in the 1975 tests." (Page 249 of NIST Report.)[6]

TABLE 5 - TENABILITY LIMITS (Page 248 of NIST Report)

	1975 TESTS[3, 4]	CURRENT[6]
Temperature	**>= 66°C**	**>= 88°C** ***(Less Conservative)***
Co Concentration	**>= .04%**	**>= .02-.03%** ***(More Conservative)***
Smoke obsc. (od/m)	**>= 0.23/m**	**>= 0.25/m** ***(The Same)***

Although the tenability criteria are different, it does not appears to explain the new result that the ionization detectors are inadequate for smoldering fires in the Living Room. In every smoldering case the tenability criteria that matters is obscuration. The obscuration tenability is virtually identical to the one used in 1975.

A better explanation for why the ionization detectors appear to be inadequate in these newer test is the one hypothesized in the earlier paper[1].

> *"Ionization detectors may have been de-sensitized over time (definitely since the early 80's) and <u>are relatively poor at detecting the kind of smoke given off by today's synthetic furnishings."</u>* [1]

Although NIST mentions that the earlier tests used cellulosic-material furnishings, while their current work used synthetic, they do not identify this factor as a possible reason for the different results that were obtained in the recent tests.

The important results from the recent tests[6], as opposed to the earlier test at Indiana Dune [3, 4], are illustrated in the following table.

TABLE 6 - 1975 RESULTS VS. CURRENT RESULTS

	1975[3, 4]		**CURRENT[6]**	
	Flaming	**Smolder**	**Flaming**	**Smolder**
Ion	Adequate	*Adequate*	Adequate	*Not Adequate*
Photo	Adequate	Adequate	Adequate	Adequate

In addition to pointing out what they perceive to be key differences, the researcher's of the current study point out some similarities between the current tests and the 1975 tests.

> *"Calibration in the FE/DE of the alarms used in the current study showed that the sensitivity of the alarms as consistent with manufacturers ratings and, on average, of equivalent to those used in the 1975 study. The average sensitivity of all alarms tested (in the current study) was 1.5 +/- 0.4 % obsc./ft., in the 1975 study, the average of all alarms tested was 1.9+/- 0.7% obsc./ft. While the average for the 1975 tests is higher the uncertainty in the data overlaps."* [6]

However, it seems inappropriate to average the sensitivity for all the detectors together. For example; assume that in one test the average ion sensitivity was 1.0*% obsc./ft.,* and the average sensitivity of the photos was 2.0*% obsc./ft.,* the overall average would be 1.5*% obsc./ft.*. Now assume that in another test the average photo sensitivity could be 1.0*% obsc./ft.,* and the average sensitivity of the ions could be 2.0*% obsc./ft.*. Once again, the overall average would be 1.5*% obsc./ft.*. As a consequence, from the first test to the second the sensitivity of the ionization would have double while the sensitivity of the photos decreased by a half. But the average would have stayed the same.

By emphasizing the overall average sensitivity, this type of critical information is hidden. In the recent testing[6] the average, as stated earlier was *1.5 +/- 0.4 % obsc./ft,* but the ionization detectors were 1.26 +/- 0.38*4 % obsc./ft* and 1.29 +/- 0.51*4 % obsc./ft*, while the photoelectric was 2.06+/- 1.3*4 % obsc./ft* . Table 7 is a breakdown of the sensitivities of the detectors used in 1975. [3, 4]

TABLE 7 – DETECTOR SENSITIVITIES FROM INDIAN DUNES (% OBS/FT.) [3, 4]

	Part One (74-75	Part Two-A (09/75)	Part Two-B (05/76)	% Change from Part One to Part Two-B
Photoelectric	1.425	1.50	2.09	+38%
Ionization	2.20	1.79	1.027	-55%
Average	1.812	1.65	1.55	-16%

Any analysis that focused on average sensitivities would have missed the fact that the ionization detectors, in the original Dunes Tests, provided by the manufacturers, kept getting more sensitive i.e. detect smoke more easily, while simultaneously the photoelectric detectors, provided by the manufacturers, kept getting less sensitive, i.e. detect smoke with more difficulty. A consequence of this type of "sensitivity adjustment" would be that the relative benefit of the photoelectric detector over the ionization detector for smoldering fires would be minimized, as the testing moved forward.

During the testing at Indiana Dunes in 1975, some of the detectors used had a sensitivity as low as 0.61% obscuration. For some reason, that was never explained, in Phase Two of the testing, "a pre-set sensitivity of 1% per foot obscuration was requested from the manufacturers".[4] This request is actually a bit troubling since 2% detectors were available to American Consumers. It is particularly troubling in light of one of the conclusion from Part One. [3]

> *"Whereas detectors set at nominal 2% per foot obscuration generally provided adequate warning, those detectors whose sensitivities were near 1% per foot (actual) provided a considerable increase in escape time for smoldering fires, The effect was much smaller for flaming fires.*[3]

If the researchers knew that 2% detectors were available to the public and the researchers knew that 2% detectors showed a considerable decrease in response, relative to 1% detectors, to smoldering fires, why did they request only 1% detectors from the manufacturers in Phase Two?

The key difference between the recent NIST testing results and the 1975 testing results is the performance of the ionization detector during the smoldering scenarios. The recent results show that the ionization detector is ineffective at detecting smoldering fires. This conclusion, regarding the importance of the ionization detector's ineffective response to smoldering fires, is supported by, and consistent with, a proper understanding of the historical studies in this area.

TABLE 8 – COMPARISON OF PAPER'S OPINION TO NIST'S OPINION

	NIST'S OPINION	AUTHOR'S OPINION
Historical Studies	Both ion and photo adequate	Photo adequate, Ion inadequate for smoldering
Recent Nist Tests	Both ion and photo adequate	Photo adequate, Ion inadequate for smoldering.
Is recent testing consistent with historical?	Yes	Yes
Is opinion supported by the data?	No	Yes

Since the ionization detector is the most common detector used in residential occupancies this result is troubling, particularly if smoldering fires are responsible for a large percentage of the fatalities in residential settings.

The Importance of Smoldering Fires.

Some people seem to feel that, given the various types of fire loads and ignition scenarios that might be present in residential settings, it is impossible to predict ahead of time that type of fire will take place, and therefore impossible to predict which type of detector is better suited for a given situation. However, others argue that the main function of a smoke detector is to alert a sleeping occupant, and that smoldering fires pose the greatest threat to sleeping occupants. "Delayed discovery, typically associated with fires that occur at night when everyone is asleep, also tends to be a characteristic of smoldering fires caused by discarded smoking materials. These smoldering fires are the leading cause of US fire fatalities and detectors are ideally designed to deal with them."[17]

Here are some quotes dealing with that issue:

- According to "Fire In The US 1983-1990" fire deaths tend to peak late at night and in the early morning hours, such as when fires caused by dropped smoking materials have been smoldering for several hours.[18]
- In a 1979 study of fatal fires, the NFPA found that, "two-thirds of the deaths in one and two fatality fires resulted from fires between the hours of 8pm and 8 am. Moreover, most of these deaths occurred in fires that gained large head starts - over 40 minutes for 38% of such deaths - before discovery.[19]
- A British Study of fatal fires broke the fires into two types. Fires estimated to have been discovered within 5 minutes of ignition (most likely to have been rapidly growing flaming fires) and for fires where the time to discovery is estimated to have been 30 minutes or more (most likely to have involved a period

of prolonged smoldering before severe flaming). There were 20 times more victims per fire for the smoldering scenarios. [20, 21]

The importance of smoldering fires is supported by information in the NIST Report

TABLE 9 FIRE TYPE AND LOCATION (Page 66 of NIST Report)[6]

LOCATION	TYPE	1ST ITEM IGNITED	FREQUENCY
Living Room	Smoldering	Furniture	372
Bed Room	Smoldering	Mattress	251
Bed Room	Flaming	Mattress	249
Living Room	Flaming	Furniture	160
Kitchen	Flaming	Cooking	142
Kitchen	Flaming	Clothing	79
Living Room	Flaming	Wire Cable	61
Living Room	Flaming	Interior Wall Covering	52
Bed Room	Flaming	Clothing	51
Kitchen	Flaming	Structural Framing	50
		TOTALS	1,467

The Number One Scenario for fatal fires is the same scenario for which the ionization detector is providing negative available safe egress time. This is compelling enough but the table probably under-represents the importance of the smoldering scenario. To determine which fires were smoldering and which fire were flaming the analysts assumed <u>that only fires started with cigarettes were smoldering fires</u>.[22, 23] All other fires were put into the flaming category.

While this assumption seems adequate for NIST to develop scenarios, this information is being used by the NFPA 72 Committee, to justify policy decisions. A Special NFPA 72 Subcommittee formed to analyze the recent NIST Report included the following statement in their analysis, "A review of Table 6. *Top fire scenarios ranked by frequency of occurrence, 1992-1996* on page 66 discloses that while smoldering fires represent the top two scenarios, smoldering fires account for 42.5% of fire deaths. It is difficult to specify one type of device over another when fatal fires are almost evenly split between smoldering and flaming fires."[24]

In actuality, many items other than cigarettes.25 can ignite smoldering fires

The following situations may give rise to smoldering combustion in porous materials:

1. Contact with a smoldering material;
2. Uniform heating (spontaneous combustion within the material);
3. Unsymmetrical heating (duct on a hot surface, material exposed to heat flux on one face; and
4. The development of a hot spot within the mass of material, e.g. as the result of an electrical fault.

It seems clear that many of the fires on this table characterized as flaming could in fact be smoldering that eventually converted to the flaming mode. In addition, neither the NFPA analyst nor the author of the NFPA 72 Report made a distinction between the typical fire that occurs when people are awake as opposed to when they are sleeping. Do people who ignited their clothing on fire while cooking need a smoke detector to alert them to the danger? It seems that a proper analysis of the data could easily justify a position that smoldering fires make up the vast majority of fatal fires that occur while occupants are asleep. Even if fatal fires were evenly split between smoldering and flaming fires, why doesn't the NFPA 72 Task Group report take into account that while photoelectric always provide positive available safe egress time, the ionization detector is providing negative available safe egress time in 25% of the scenarios?

<u>Summary of Information in Part One</u>

The information in Part One can be used to develop the following syllogism:

IF: Ionization detectors are extremely poor at detecting smoldering smoke from synthetic furnishings, and

IF: Ionization detectors are the most common detector installed in residential occupancies, and

IF: Smoke detectors provide the greatest benefit when occupants are sleeping, and

IF: Smoldering fires are the most common fatal scenarios while people are sleeping,

THEN: Ionization detectors have not provided a substantial benefit to the reduction in fire deaths over the past 25 years because they do not provide a substantial benefit when synthetic materials smolder and these scenarios comprise a large percentage of the fatal fires when people are sleeping.

However, this syllogism would appear to be contradicted by the statistical evidence as cited by NIST so prominently in their introduction. Part Two will look at the available statistics.

PART TWO – STATISTICAL ANALYSIS

The conclusion of the syllogism at the end of Part One appears to be contradicted by two commonly held assumptions:

First - Smoke detector usage rose from 10% in 1975 to 95% in 2000 while home fire deaths cut in ½. •"Thus the home smoke alarm is credited as the greatest success story in fire safety in the last part of the 20th century, because it alone represented a highly effective fire safety technology with leverage on most of the fire death problem that went from token usage to nearly universal usage in a remarkably short time." [6]

Second –A frequently cited statistic from the NFPA " If a home fire occurs, smoke alarms reduce the risk of death by 40-50%. [26]

These two statistics seem to contradict the syllogism because any benefit derived from smoke detectors over the past 25 years is derived from primarily ionization detectors, which are approximately 90% of the installed detectors.[27] However; a proper analysis of all available statistics provides some support for the syllogism.

Analysis of 1st Statistic – Fire deaths have decease over past 20 years.

First, it is important to understand that concurrent with an increase in the use of smoke detectors; there were a large number of other actions implemented to reduce fire deaths.

Improvements in Emergency Care and Burn Care

"At the time of America Burning (1975) there were 12 full spectrum burn centers. By 1999 there were over 100 burn centers with 25 being full spectrum. On a yearly basis, deaths, once the victim has been placed into the burn care system, have decreased from around 4,000 to 1,000." [28]

- This reduction may be partially due to the fact that smoke detectors and FF's SCBA allow victims to be rescued earlier. It has been my personal experience that FFs SCBA has made a significant contribution to victims survival rate.

Reduction in Smoking

"Stopping smoking can significantly reduce the devastation, injury and cost by fire. 2/3 of all U.S. reductions in fire fatalities related to smoking from 1984 – 1995 were attributed to reductions in cigarette consumption. [29]

The most important part of the smoking-material fire problem-the number of structure fires-has declined by two-thirds, or 66 percent, since 1980, while the number of civilian deaths has dropped by 49 percent from the high in 1981 and 44 percent since tracking began in 1980. However, deaths per 100 smoking-material fires were 66 percent higher in 1995 than they were in 1980.[30]

This second statistic is important since it allows one to isolate the items that would reduce fatalities due to preventing ignition from those that reduce deaths due to factors that affect outcomes once ignition occurs. It is self apparent that fire fatalities from cigarette ignites fires would be reduced over time due to a reduction in the number of smokers as well as regulations that would increase the number of mattresses and furniture resistant to cigarette ignition. If smoke detectors were also contributing to the reduction then there should be a reduction in the number of fatalities that are occurring after ignition occurs. The following two tables allow one to investigate this area of investigation.

TABLE 10 - FATALITIES AND INJURIES FROM CIGARETTE FIRES (5 YEAR ROLLING AVE/PER 100 FIRES) [31]

	1980-84	1984-88	1988-92	1992-96	1997-2001
Fatalities	3.0	3.5	3.6	3.7	3.5
Injuries	6.5	7.7	9.2	9.3	8.3

Evidently, smoke detectors have had virtually no impact on the number of fatalities from cigarette fires, once the fire was ignited**. In fact, the number of people being injured and killed in fires started by cigarettes was increasing at the same time that the number of installed smoke detectors was increasing dramatically.** . This seems counterintuitive unless one takes into account that at the same time that the amount of synthetic furniture was gradually increasing UL allowed slightly less sensitive ionization detectors to be introduced into the marketplace. This will be discussed in detail in Part Three.

Improvements in Heating Appliances[32]

- From 1980 to 2001 fire deaths from home heating declined from 840 to 220. A reduction of 73%.
- Fatalities from fixed space heaters went from 310 (1980) to 80 (2001). A reduction of 74%.
- In 2001 heating equipment fires accounted for 15% of all reported fires. This was down from 30% in the years 1980-1985. It was a high as 22% as recently as 1989.

Improvements in Furnishings. [33]

- Mattress and Bedding Fire Fatalities have declined from 937 (1980) to 398 (1998). Down 57%,
- Upholstered Furniture Fire Fatalities have declined from 1,386 (1980) to 550 (1998). Down 60%.

Improvements in Building Codes

- Increased use of sprinklers (1% homes, 7% apts.). [34]
- Improvements in wiring, fire rated construction, etc.

It is interesting to note that fire fatalities were decreasing even before the increased use of smoke detectors. They also continued to decrease after the rate of increase leveled off. It does not appear the rate of decrease in fire deaths corresponds to the rate of increase in the usage of smoke detectors.

TABLE 11- TRENDS IN FIRE DEATHS VS. DETECTOR USAGE

	1965-1975	**1977-1987**	**1992-2002**
Increase In % of Homes with Detector (from beginning to end of time period) [DD]	<4% - 10%	22% - 82%	90% - 96%
% Decrease in Fire Deaths per Million People (from beginning to end of time period)	-27% (Residential) National Safety Council)	-29% (All) NFPA	-25% (All) NFPA

Notes: For 65-75 only residential deaths were considered. The data was obtained from National Safety Council estimates.[35] For 77-87 and 92-02 all deaths were considered, data was obtained from NFPA estimates.[36] Direct comparisons are difficult because I could not find any one source of data that encompassed the entire period of interest. However, the data from the beginning of one period to the end of that period is the same.

It can be reasonably inferred, from this table, that the rate of reduction in fire deaths, over the past 30 years, was relatively independent of the rate of increase in smoke detector usage. Fire deaths were decreasing prior to any sizeable increase in smoke detector usage (-27%) and fire deaths continued to decrease even after smoke detectors achieved almost universal coverage (-25%). If smoke detectors were the most important reason for the decrease in fire deaths over the past 25 years as NIST asserts, then the rate of decrease should have been greatest during the time period when smoke detector usage was increasing the most. It does not appear that the rate of decrease was substantially different during this time period (-29%). While I have no doubt that smoke detectors have contributed to the reduction in fire deaths, it would appear that many other factors contributed as much, if not more, to the reduction.

Other researchers have noted this long-term trend, as well as the fact that the decline did not always track consistently with an increase in detector usage. "Up to 1982, numbers of fires and deaths – whether total or residential structures in particular – have shown a strong long-term trend of decline. For example; from 1980 to 1982, total; fires declined 15%, deaths in those fires, residential structure fires 11%, and deaths in those fires 9%. Similar declines occurred in most years of the 1970's, as far as we can tell. From 1982 to 1986 however, numbers of fires has fallen more slowly and numbers of deaths have been essentially constant."[37] (Note: The decline in fire deaths does not appear to have always tracked consistently with an increase in detector usage. From 1982-1986 smoke detector usage increased from 59%-77%.[26])

Analysis of 2nd Statistic – Smoke detectors reduce risk by 40-50%.

This is another one of those statistics that appears compelling but which actually has some troubling aspects. For one thing, from 99-01 the reduction in risk for apartments & condos was only 7%. It is hard to believe that "the greatest success story in fire safety in the last part of the 20th century" only reduce your risk of dying by 7%.[26] In addition, beginning in 1999 an increasing amount of data has been collected in NFIRS (national Fire Incident reporting System) Version 5.0.[38] In 2001 using this new data the NFPA estimated reduction was only 21%. It is possible that the previous estimates, which incorporated assumptions to compensate for incomplete data, were overly optimistic? In any case, researchers cannot identify how much of the reduction in risk is not due to the effectiveness of the detector but rather due to occupant characteristic that go along with owning a smoke detector: higher income, newer construction, better evacuation plans etc? All of these factors would contribute to a reduction in fire risk.[39] As a consequence, the actual reduction in risk due to the effectiveness of the detector is actually much less that 21%. This minor reduction in risk hardly justifies NIST's description of smoke detectors, as the "greatest success story in fire safety in the last part of the 20th century".[6]

There is another statistic, which, appears to support the syllogism. "Smoke detectors are much less likely to be present when there are fatalities. Detectors do indeed make a difference. Yet in 19% of the reported residential fire deaths in 1994, a detector did operate; in 1988, it was 9%. In some cases the detector may have gone off too late to help the victim, or the victim may have been too incapacitated to react. But the % of deaths with detectors, especially the upward trend, is somewhat disturbing since there is a widespread belief that an operating detector will save lives. Further study is needed to show what other factors were involved with these deaths."[40]

TABLE 12 – FIRES WITH WORKING DETECTORS [41, 42, 43]

	% OF FATAL FIRES WITH WORKING DETECTORS	% OF HOMES WITH DETECTORS	% OF FIRES WITH WORKING DETECTORS
1988	9%	81%	38%
1990	19%	86%	42%
1994	19%	93%	49%
1996	21%	93%	52%
1998	29%	94%	55%
2001	39%	95%	55%

While there will always be a certain percentage of people who cannot be saved by smoke detectors, e.g. the handicapped, those intimate with the fire etc., there is no reason to believe that the number of those people quadrupled between 1988 and 2001. In addition, while the number of fires with working detectors increase approximately in proportion to the increase in the number of detectors installed, the increase in the % of fatal fires with working detectors far exceeds it. Although the USFA never did study this issue, the information in this paper does point to a plausible explanation. If ionization detectors are relatively insensitive to smoldering smoke then the gradual introduction of less sensitive, i.e. higher nominal sensitivity, ionization detectors into the marketplace, starting in the late 80's, would be expected to gradually increase the number of people dying due to delayed detection of smoldering smoke. (The UL allowance of less sensitive detectors will be analyzed in Part Three.)

It appears that a careful review of the available statistics indicates that smoke detectors are not nearly as effective as many people assume. In fact, the statistics seem to indicate that there is a “problem” with the smoke detectors that have been used for the past 20 years. The statistics do not indicate that they, i.e. ionization detectors, do not work at all. But, they do seem to indicate that they do not appear to work as efficiently as they should, or as efficiently as they are claimed to be by many experts as well as manufacturers. It is important to remind the readers of this paper that when talking about a “problem” with detectors, one is actually talking about a problem with “ionization” detectors, 89% of all detectors. [26]

PART THREE - TESTING AND APPROVAL PROCESS

The number on the back of a smoke detector that provides a smoke obscuration measurement, such as 2.0+/-0.2% obscuration/foot, is not intended to give an approximate obscuration at which the detector will operate. Actually this number is obtained during a sensitivity/calibration test. In the U.L. 217[2] test, the smoke detector is placed in a "smoke" box 6ft x 1.5ft x 1.5 ft and smoke is blown toward the smoke detector by a fan. Another test is run later on in the testing process where the smoke detector is placed in a room on the ceiling and walls 17.7 feet away from the fire. The detectors are subjected to five sources of smoke and have to detect the smoke within a certain time frame. The five tests are summarized below.

TABLE 13: SUMMARY OF UL 217 FIRE TESTS[2]

Test Number	**Combustible**	**Detector Must Respond** Within	**Maximum Obscuration Allowed**	**Time of Maximum Obscuration**
A	1.5 oz Shredded Newsprint*	4 min.	28 %	100 sec.
B	6 x 6 2.5 in. Layered Fir Wood	4 min.	12 %	160 sec.
C	30 ml Regular Leaded Gasoline*	3 min.	14 %	180 sec.
D	1 oz Foam Polystyrene Packing	2 min.	13 %	70 sec.
E	Ponderosa Pine Sticks Over Hotplate**	70 min.	10 %	N/A

* Flaming Fire ** Smoldering Fire

The reasons for the selection of White Pine as the material to be utilized in the smoldering smoke test are outlined in a 1979 article by Harpe and Christian.[16] They stated that,

> "In order to produce a first generation test method in a reasonable time period, consideration was limited to a single class of material. The choice of that material was aided by the fact that among many combinations of materials commonly used in upholstery and bedding, cotton fabric and padding seem to be the most easily ignited in the

smoldering mode by cigarettes. Accordingly, the test development was based on smoldering fires in cotton mattresses."

These researchers found that ponderosa pine sticks gave off the type of smoke characteristics that most nearly resembled the smoke characteristics of the smoldering cotton mattress fires. Unfortunately, this "first generation" smoldering test, as describe by the developers, became the "only generation" smoldering test. If all smoldering material produced the same “smoke profile” this might be adequate, unfortunately, they do not. If it is appropriate to test multiple materials in the flaming mode, isn't appropriate to test multiple materials in the smoldering mode?

Schucard.44 who measured the actual obscuration that caused smoke detectors to go into alarm, during smoldering fires, versus the UL Smoke Box Sensitivity Test, published an important study several months prior to Harpe and Christian’s. His tests were performed in a sealed room measuring 12 feet by 11 feet with an 8-foot ceiling, to simulate a small bedroom. Materials burned included Douglas Fir, as originally proposed, and white pine, as later adopted in UL 217, as well as common households throw pillows consisting of 65% polyester, 35% dacron, and 4% cotton, and a standard urethane mattress with synthetic cotton covering. The results are listed in Table 14.

TABLE 14 - SMOKE BOX SENS. VS. SMOLDERING ROOM FIRE SENS.

ALARM POINTS (% Obscuration per foot)					
Type	**Smoke Box Sensitivity**	**Test #5A-Douglas Fir**	***Test #11B White Pine***	**Test #18D Urethane**	**Test #16A Polyester**
Ionization	-	7.2	*4.8*	18.8	12.1
Ionization	.85	7.7	*6.2*	20.0	N/A
Ionization	L1	Not Recorded	*7.4*	21.6	
Ionization	1.3	11.2	*8.9*	20.0	21.8
Ionization	3.7	18.0	*9.6*	N/A	28.4
Ionization	1.78	15.6	*10.4*	N/A	26.8
Ionization	-	10.7	*10.6*	N/A	N/A
Ionization	-	18.9	*11.0*	N/A	33.0
Ionization	4.0	N/A	*N/A*	N/A	N/A
Photoelectric	1.5	1.6	*1.3*	3.6	2.8
Photoelectric	1.23	2.2	*1.4*	6.5	6.8
Photoelectric	1.68	.85	*1.2*	0.5	1.0
Ave Ion	2.2	14	*8**	20	25
Ave Photo	1.5	1.5	*1.3*	3.3	3.4

***** item selected for smoldering smoke test N/A indicates "no response."

Table 14 clearly illustrates several important points.

1. The sensitivity rating on the back of the detector is not necessarily indicative of the obscuration level that the detector will activate at in a real fire.

2. The photoelectric detector appears to respond much closer to the sensitivity level listed on the detector than the ionization detector.
3. The only material that, on average, alarmed the ionization detector below 10% obscuration was White Pine. This is important since White Pine is the material that is used during the smoldering fire test by Underwriters Laboratories where the detector must activate before 10% obscuration
4. In view of the above, UL should have developed a smoldering smoke profile that “matched” the smoke given off by smoldering synthetic material. Instead, they use White pine, which provides results vastly more optimistic than do more realistic fuels.

Furthermore, one could conclude that. If it is the smoldering fire that kills most people at night it seems critical that we test at least as many different types of items during the smoldering test that we use during the flaming test. It is especially troubling that Schucard’s results were published in 1979, prior to the smoldering test being incorporated into UL217, yet to date UL has not remedied the problem.

The following conclusions appear to be justified.

- Ionization detectors that pass the UL 217 smoldering test may not, in fact, be able to detect the smoke produced by smoldering fires involving synthetic material before untenable levels are exceeded.

- The inability of the current smoldering test to accurately “mimic” modern furniture was recognized as early as the late 70’s. The results of the recent NIST Tests that show the ionization detector responding at obscuration levels of approximately 20% corroborates Schucard’s finding of 1979.

- A similar problem may exist in Europe, even though EN54[45], The European Approval Standard, contains a smoldering synthetic scenario but passing criteria is approximately 17% obsc./ft., which seems unreasonably high.

Unintentionally, in an effort to address the nuisance alarm issue, The UL217 Committee may have exacerbated the problem. It appears that to allow less sensitive smoke detectors to be manufactured UL had to alter the smoldering test to make it easier to pass.

TABLE 15 - HISTORY OF UL 217 SMOKE DETECTOR TEST

<table>
<tr><td><1976</td><td>2 Separate standards: UL167 [46] for Ion and UL168 [47] for Photo</td></tr>
<tr><td>1976</td><td>UL217 created using 4 flaming fires from UL167.
Prod Sens: 0.2-4.0 gray smoke, 0.5 – 10% for black smoke</td></tr>
<tr><td>1979</td><td>Smoldering test added – 7% criteria. (Typical ion detector increased in sensitivity in order to pass this new test.)</td></tr>
<tr><td>Early 80's</td><td>Massive nuisance alarm problems cause UL to investigate possible desensitization of detectors.</td></tr>
<tr><td colspan="2">The following changes required less sensitive detectors to be manufactured .</td></tr>
<tr><td>01/84</td><td>Minimum sensitivity for gray smoke increased from 0.2% to 0.5%. (Forces increase in average sensitivity.)</td></tr>
<tr><td>05/84</td><td>No response <0.5% in Smoldering Test. Max.</td></tr>
<tr><td colspan="2">The following changes appear to have been instituted to allow these new and less sensitive detectors to keep passing the UL Tests.

1. The biggest changes were made to smoldering tests. Logically it would appear that this was done in order to allow the less sensitive ionization detectors to pass.
2. There were also changes to the "black smoke" test. This would have been done to allow less sensitive photoelectric detectors to pass UL test.</td></tr>
<tr><td>05/84</td><td>Smoldering Profile "shifted" to the "smaller more numerous particle" portion of the profile.
UL also instituted a slower build-up allowing more time for smoke to enter the detector</td></tr>
<tr><td>87-88</td><td>Passing Criteria of Smoldering Test increased from 7% to 10%.</td></tr>
<tr><td>88</td><td>Max in "Black Smoke" Smoke Box test increased from 10% to 13%.</td></tr>
<tr><td colspan="2">While changes were made to accommodate both ionization and photoelectric detectors, the consequences were not the same.
It is very common for fires that occur in residential settings to produce smoldering smoke. As a consequence changing a detectors ability to detect this kind of smoke is critical.
It is very uncommon for residential fires to produce the kind of "black smoke" produced by kerosene, which is the source of smoke in the UL smoke box test. As a consequence changing a detectors ability to detect this kind of smoke is not critical</td></tr>
</table>

Based on the History of UL 217 as well as Schucard's information in Table 14, the following scenario seems logical.

1) The ionization detectors at Indiana Dunes are set to a sensitivity of approximately 1.2 – 1.5. (See Table 7.)
2) UL 217 incorporate the new smoldering test with a sensitivity setting of 7%. The manufacturers have to increase the average sensitivity to less than 1.0 in order to pass this new test.[48] Due to massive amounts of nuisance alarms. UL requires manufacturers to make less sensitive detectors by increasing the minimum sensitivity of the production window from 0.2 to 0.5%. The new less sensitive ionization detectors probably had trouble passing the smoldering test with a 7% passing

criteria. UL Changes the passing criteria from 7% to 10&. These changes allow the manufacturers to increase sensitivity to approximately. 1.0 – 1.5 and still pass the smoldering test by responding to white pine before 10% obscuration

3) Unfortunately, according to Schucard[43], this level of sensitivity does not allow an ionization detector to detect smoldering smoke from synthetic material until 18-25%. This is approximately the same obscuration that the recent NIST testing[6] observed.

In my opinion, this analysis of the UL Approval Test, is consistent with my analysis of the statistical evidence as well as my analysis of the historical studies and the recent NIST tests. Taken together they comprise an overwhelming case to conclude that ionization are not very effective life safety devices.

CONCLUSIONS & RECOMMENDATIONS

Conclusions Regarding the effectiveness of smoke detectors

For residential fire scenarios:

- Ionization detectors are best for flaming fires, while photoelectric detectors are almost as good and still effective because they provide adequate warning of a fire.
- Photoelectric are best for smoldering fires, but ionization detectors are not effective since they will probably not provide adequate warning of a fire.

For non-residential fire scenarios:

- There may be situations, especially in commercial or industrial occupancies, where ionization detectors are preferred because smoldering fires are not anticipated.

Combination detectors, i.e., detectors utilizing both ionization and photoelectric sensors, could be part of the solution but certain areas of concern exist.[9, 49]

- Combination detectors could still experience excessive nuisance alarms, particularly near kitchens, due to ion technology.
- Both sensing mechanisms can be de-sensitized and the combined detector can still pass UL test. This was demonstrated in the recent NIST study, where appeared ineffective for flaming fires in the living room.
- Photoelectric detectors appear acceptable for all kinds of fires in a residential setting, so it may not be necessary to use the more expensive dual-sensor technology.

It is important to clarify what "effective" means in the earlier paragraph. To be considered effective, we should demand more from a smoke detector than that "it is better than nothing". We should demand that it detect most fires, early enough to provide occupants adequate time to escape. In particular a residential smoke detector should detect those kinds of fires that are most likely to occur while occupants are sleeping as well as those kinds of fire that are causing the most fatalities, i.e. smoldering fires. Since the overwhelming evidence indicates that ionization detectors cannot do this they should not be considered "effective". One smoke detector user's manuals contain language similar to the following: "Smoke Alarms are designed to provide early warning of fires if located, installed and cared for as described in the user's manual, and if smoke reaches them."[50] In these tests, all those conditions were met yet the ionization detectors did not give "early warning" for smoldering fires. Doesn't that mean that the ionization detector has an inherent design flaw, since it does not perform in a manner for which it was designed? If there were no other inexpensive alternative we might accept the ionization detector as the best that can be used. However, there is another in-expensive option, i.e. the photoelectric detector. The photoelectric detector is "effective"

<u>Conclusions Regarding the Validity of UL217</u>

The UL 217 Smoldering Fire Test is flawed because the material it uses in the testing process, White Pine, provides smoke particles, which are exceptionally easy for ionization detectors to sense, in contrast to realistic occupant fuels, such as polyurethane mattresses, for which ionization detectors are exceptionally insensitive.

<u>Recommendations For UL 217</u>

A "2nd Generation" smoldering test, should be developed to replace, or be in addition to, the current UL 217 Smoldering Test. This test should reflect the type of smoke given off by mattresses and furniture. Using synthetic material. In addition, the smoke growth rate should approximate the growth rate of the smoldering fires in the recent NIST tests, reaching 10%obs/ft in approximately 45 to 60 minutes. It might also be helpful for UL to test detectors ability to respond to smoke when located in an adjacent room. (Millions of detectors are installed in hallways and common areas and would have to be able to detect smoke in this setting.) This is necessary to account for the "smoke aging" effect that occurs when smoke travels from one room to another. This effect would also negatively impact on an ionization detectors ability to respond in an effective manner.[1]

Avoid at all costs the temptation to desensitize detectors even further in an attempt to alleviate the nuisance alarm problem. This dangerous recommendation has been suggested by some analysts.[25] If this were done it would exacerbate an already substantial problem regarding ionization's response to smoldering fires.

If UL made these changes, it might not be necessary to favor one type of detector technology over another. It could be reasonable to assume that any detector that passed these more stringent and valid tests would be "effective" in a residential setting. (Based on the information in this paper it is unlikely that a typical ionization detector could pass these more stringent tests.) However, in the absence of these types of changes, it cannot be assumed that a detector that passes the UL test is effective. As a consequence, it is necessary to specify a specific detector technology, photoelectric, in installation guidelines.

Installation Recommendations

In residential occupancies, improved recommendations should be issued by NFPA for siting of smoke detectors. For new construction, these should include:

1. At least one detector per level
   a. Outside each bedroom area.
   b. On the ceiling near the bottom of a stairwell located in such a manner to intercept smoke before it travels into the stairwell.
2. A detector in every bedroom.
3. If any room exceeds 400 ft^2, then a detector is required in that room as well,
4. Additional detectors are needed to insure that the door to a room is within 20 ft of a detector.
5. All detectors to be interconnected with a battery back up.
6. **All detectors should contain a photoelectric sensor.**
7. Detector should be located to avoid nuisance sources to the greatest extent possible, e.g., avoiding areas near kitchens and bathrooms. (Although switching to photoelectric technology should greatly reduce nuisance alarms it would be even better to have smoke detectors with easily accessible "silence buttons" for these locations.)

Comments:

- The rationale justifying #6 is contained in this paper. For those who find this recommendation too drastic, at least consider mandating photoelectric detectors in residential occupancies that are sprinklered. Once these occupancies are sprinkled the only real threat is from smoldering fires.
- The rationale justifying #3 and #4 might not be quite so obvious. It seems reasonable to use the same "spacing guidelines for residential detectors that exist for commercial detectors, since they have to pass the same fire tests. NFPA 72 recommends a maximum spacing of approximately 30 feet for commercial detectors. (This insures no area will be more than approximately 21-22 feet from a detector.) In addition two different manufacturers user's manuals recommend the following: "2 detectors if corridor exceeds 30 feet"[50] and "2 detectors if corridor exceeds 40 feet."[51] Given this information, some language similar to the language is #3 and #4 appears justified.

For existing houses, these should include:

1. At least one detector per level
   a. Outside each bedroom area.
   b. On the ceiling near the bottom of a stairwell located in such a manner to intercept smoke before it travels into the stairwell.
2. A detector in every bedroom.
3. **All detectors should contain a photoelectric sensor.**
4. Detector should be located to avoid nuisance sources to the greatest extent possible, e.g., avoiding areas near kitchens and bathrooms. . (Although switching to photoelectric technology should greatly reduce nuisance alarms it

would be even better to have smoke detectors with easily accessible "silence buttons" for these locations.)

Comment:

- Since it is difficult to get homeowners to install the detectors required now it is unlikely they would willingly go beyond these requirements.
- Until UL217 is changed it is difficult deal with the ionization/smoldering problem in existing structures. The misinformation that has been saturating the public consciousness on this issue for so long has led to a lack of demand for any one type of detector. As a consequence, many stores do not even carry photoelectric or combination detectors. If the problem cannot be addressed by a massive public education campaign, then more regulatory action may be required. The ionization detectors should be phased out, as soon as possible. At the same time we must educate the public to maintain what they have, since it is, after all, "better than nothing".

Similar recommendations to the ones listed above were proposed to the NFPA 72 Technical Committee in 1999.[52] After reviewing the supporting material, which did not differ substantially from the material contained in this paper, the Committee gave this reply in response to my request that all residential detectors should be photoelectric.

"The committee feels that the data cited does not make a sufficiently compelling case for banning an entire technology. There would need to be clear evidence of a compelling hazard in order to justify a change that would deny ionization technology to consumers and to literally put companies out of business. A comprehensive testing project is being considered by the US Consumer Safety Product Commission (CPSC). If these tests indicate a compelling reason to ban ionization technology the committee will reconsider."[53]

It is possible that a committee responsible for a state or local building or fire code might reach a different conclusion about how compelling the evidence is regarding this issue. Perhaps this committee will decide to giver less weight to the concern that consumers will be denied ionization technology. Perhaps this committee will decide that most consumer are not even aware of the difference between ionization and photoelectric technology so consumer demand for ionization technology does not even exist. Perhaps this committee will give a higher priority to the safety of the citizen's they represent than they do to the financial well being of manufacturers of smoke detectors. Perhaps they will agree with the logic in this paper that the NIST Tests indicate a compelling reason to ban ionization technology. Perhaps they will reach the same decision that the NFPA Committee reached. The point is that local and state committees cannot delegate this responsibility to an NFPA Committee.

If the information and conclusions in this paper are valid, the good news is that by switching from ionization to photoelectric technology, smoke detectors can finally realize their full potential and fire deaths can be reduced by hundreds of lives per year. Unfortunately, the bad news is that these lives could have been saved much earlier.

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APPENDIX A

SUMMARY OF SMOKE DETECTOR STUDIES

SUMMARY OF SMOKE DETECTOR STUDIES				
TESTING AGENCY	**YEAR**	**SYNTHETIC MATERIAL**	**DURATION OF SMOLDERING**	**COMMENTS**
#1 - National Research Council of Canada[1]	1962	N/A		This was a study (no testing) that just used judgement to estimate the potential effectiveness of detectors.
#2 - Los Angeles Fire Dept. [2]	1960	NO		This used heat detectors and older photoelectric technology
#3 - Bloomington MN Fire Dept. [3]	1969	NO		Remote smoke detectors better than nearby heat detectors. Older technology..
According to the NIST Study, published in Fire Journal (Reference 7 of paper), the smoke detectors used in the next test were "significantly improved over those used in prior test and were essentially equal to that of current devices." (This does not appear to be tru for photoelectric detectors, which are greatly improved due to "open" design allowed by the use of LED technology.)				
#4 - Japan Housing Corp[4]	1974	?		Smoke detectors better than heat detectors.
#5 - Factory Mutual Study (Heskestad) [5]	1974	YES	>30 MINS.	Ion good for flaming bad for smoldering Photo good for smoldering bad for flaming (Photo flaw could be corrected if "smoke entry problem corrected. Ion flaw inherent in technology.) Smoke entry problem was corrected in early 80's. One could use this study to justify claim that current photoelectrics are superior to current ionizations.
#6 - Indiana Dunes[6,7]	1976	NO	> 30 MINS.	Smoke Detectors better than heat detectors and one detector per level desireable.
#7 - Massachusetts Analysis of Dunes[8]	1976	N/A	N/A	A detector per level will provide 3 minutes of escape time 89% of the time. It was analysis of Dunes data.
#8 - Edmonton FD [9]	1976	UNK.	>60 MINS.	Both ion and photo provide considerable life safety. In smoldering ion may go off too late.
#9 – Minneapolis Fire Dept. [*-10]	1978	YES	<10 MINS.	Both Ion and Photo gave good early warning if smoke could reach detector.
#10 - Australian Dept. of Housing and Const. [11]	1979	UNK	FLAMING FIRE	All Smoke detectors adequate and smoke detectors better than heat detectors. This testing involved only flaming fires. (According to 86 Study, #13.)

SUMMARY OF SMOKE DETECTOR STUDIES (Continued)				
TESTING AGENCY	**YEAR**	**SYNTHETIC MATERIAL**	**DURATION OF SMOLDERING**	**COMMENTS**
#11 - CAL CHIEFS LA Fire[12, 13, 14]	1978	YES	>30 MINS.	Smoke detectors more reliable than heat detectors. NIST concluded both types of detectors adequate. *(Modern furniture was used, LAFD and IAFC Reps favor photo-electrics based on the results.)*
#12 - Fire Res Station (Great Britain) [15]	1978	YES	>30 MINS.	Both ion and photo respond rapidly to flaming. Ion was not adequate in smoldering
#13 – Smoldering Fires (Australia) [16]	1986	YES	< 10 MINS.	Photoelectric detectors provided adequate escape time for most fires. Ionization generally were inadequate. (This study was published in Fire Technology.)
#14 - Norwegian Fire Research Lab Study [17]	1991	YES	> 30 MINS.	There are reasons to indicate ions are inadequate for smoldering fires. Ion only 15-20 secs better than photo in flaming fires. Advantage only beneficial under extraordinary circumstances.
#15 - Smoke Alarms In Typical Dwelling Fire Research (GB) [18]	1997	(Part 1) YES	> 30 MINS.	Ion cannot be guaranteed to detect smoldering fire. Ion better at flaming and difference could be critical. (The smoldering fires smoldered for > 30 min.)
#16 - Practical Comparison of Alarms Fire Research (GB) [19]	1997	(Part 2) YES	<15 MINS.	Both Ion and Photo Adequate (In Pt 2 the “smoldering fire” appeared to smolder for a much shorter period than in Pt 1. For some unexplained reasons the researchers altered the mechanism they used to ignite the smoldering fires.)
#17 - Simplex Study- [20]	2001	UL 268 TESTS	UL 268 TESTS	Ion detector only slightly better for flaming. Photo provides clear advantage over ion for smoldering fires
#18 - KEMANO FIRE STUDIES NRC-Canada[21]	2003	YES	< 15 MINS.	Combination Smoke Alarms best. Ion faster for flaming and Photo better for smoldering. All seemed adequate for evacuation. The ULC approved detectors may be more sensitive than UL approved detectors since fire test are different.

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